level interconnects, fill the vias, form xerogel layer, pattern interconnects in the xerogel, deposit blanket metal, polish to complete interconnects, and deposit overlying dielectric.

Slot geometry preferred embodiment

A further preferred embodiment deposits oxide over the interconnects, etches trenches between minimally spaced interconnects, and then fills the trenches with xerogel by a spin on and etchback. In particular, FIGS. 4a–c illustrate this approach. FIG. 4a shows trenches 341 which have been etched in planarized oxide 440 and between minimally spaced adjacent interconnects 430. Again, interconnects 430 may be 700 nm high and 200 nm wide with the minimal spacing of 200 nm.

Next, spin on a xerogel precursor solution which fills trenches 341 plus the horizontal portions of oxide 440, and then react to form the gel and dry to form xerogel 442. Etchback xerogel 442 (fluorine-based plasma) to remove all of the xerogel outside of the trenches; see FIG. 4b.

Deposit and planarize thick oxide 460 on oxide 440 and xerogel 442, the poor adhesion to xerogel 442 is not a problem because of the large oxide 440 area. Etch vias in oxide 460 down to interconnects 430, and deposit and pattern metal to form interconnects 470; see FIG. 4c. This approach only has xerogel in minimal gaps between adjacent interconnects; of course, this is where the xerogel has the most effect in lowering capacitive coupling.

Interconnects 430 could have a silicon nitride liner; this permits selective oxide etching the trenches in the minimal gaps between adjacent interconnects and leave the nitride liner to protect xerogel 442 from metal interconnects 430. However, such a liner will increase the effective dielectric constant between the adjacent interconnects.

Surface filling adhesion

HSQ adhesion layer 144 of the preferred embodiments could be replaced by layers of other materials which also have good gap fill properties. In particular, the average pore size of xerogel varies with the dielectric constant, and for dielectric constants about 1.5 to 2.0 the average pore size is on the order of 10 to 25 nm. Thus a material which is depositable to fill open pores of this size at the surface will have a large contact area to bind to the xerogel plus will have mechanical interlocking to increase adhesion. FIG. 5 illustrates in cross sectional elevation view the open pore filling. FIG. 5 shows xerogel 510 including interior pores 512 away from the surface and pores 514–516 open at the surface; gapfill material layer 520 fills essentially all of pore 516 but only roughly half of pore 514. If the gapfill material fills roughly 50% or more of the volume of the average open pores at the surface, then the contact area increase and mechanical interlocking are significant. So a gapfilling material which provides a good surface for subsequent thick dielectric deposition may be used as an adhesion layer material.

For plasma enhanced TEOS oxide (or fluorinated oxide) thick dielectric, the following materials should sufficiently fill the open pores at the xerogel surface and provide the adhesion layer: HSQ, subatmospheric ozone TEOS based CVD (SACVD), methyl silsesquioxane, Flow Fill oxide (spin on silanol from silane in hydrogen peroxide at a temperature of 0° C.), and so forth.

Surface activation adhesion

Rather than apply a pore filling material such as HSQ 144 to xerogel 142 as in previous preferred embodiments to provide adhesion for deposited dielectric, an alternative preferred embodiment enhances the surface adhesion of xerogel by activating the xerogel surface with a plasma of 10–90% hydrogen and remainder argon for 1 minute with a pressure in the range of 0.1–5 Torr. The low energy plasma hydrogen removes the surface methyl groups of the hydrophobic xerogel with a net reaction such as:

$$-Si(CH3)3 + 6H \rightarrow SiH3 + 3CH4$$

The hydrided silicon surface provides good adhesion to both deposited (fluorinated) oxides and other dielectrics such as organic polymers like parylenes.

Further, the hydrogen plasma treatment can be performed in the same chamber as the subsequent plasma-enhanced oxide deposition; so the hydrogen plasma adds little processing complexity.

The plasma activated xerogel surface also provides good adhesion for deposition of barriers such as TiN and Ta2N as used in the previously-described damascene interconnect structure.

Plasma surface treatment with plasmas based on other source gasses such as NH3, 02, . . . also activate the surface by reactions like:

$$-Si(CH3)3 + NH3 \rightarrow Si(NH2)3 + CH4$$

$$-Si(CH3)3 + O2 \rightarrow SiO + CO2 + H2O$$
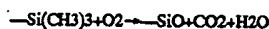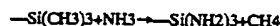
Surface shell adhesion

An alternative xerogel surface enhancement collapses a thin layer of the xerogel at the surface to form a relatively continuous shell; the shell provides a large contact area for deposited layers. See FIG. 6 illustrating the continuous surface of the shell with collapsed pores near the surface. To form the shell, exposes the xerogel surface to ion beam bombardment. Typically, an ion implanter using an argon ion beam with a dose of $10^{16}/cm^2$ and an ion energy of 20 keV; alternatively, an argon plasma could provide the ion bombardment. The hard shell will be about 20–50 nm thick. The hard shell provides good surface adhesion for plasma-enhanced deposited oxide.

In effect, if the average pore diameter were D, then the portion of the xerogel within a distance of 2D of the surface would have a porosity (ratio of total pore volume to total volume) of much less than half of the porosity away from the surface.

Gel drying

The drying of the gel in foregoing preferred embodiment step (12) could also be accomplished at other temperatures and with other reducing atmospheres at various pressures. The reducing atmosphere apparently helps remove residual adsorbants which may be partially oxidized. This treatment brings the dielectric constant down to a stable minimum for the xerogel.

In particular, heating in the range of 400–500° C. for 1–60 minutes suffices for xerogel thicknesses up to 1 μm with the longer times for the lower temperatures. Typically, integrated circuit processes will have a thermal budget and an upper limit for temperature, and thus a lower temperature but longer drying may be required. However, drying with the same conditions as used for other heat treatments, such as 430° C. for 30 minutes aluminum sintering in forming gas, would be convenient.

The reducing atmosphere could be at a pressure of 1 mTorr to 10 Torr and the gasses could be H2 with an inert gas (N2, Ar, He, . . .) in various proportions. Other reducing gasses such as CH4, NH3, . . . are possible.

Viscosity

Spin on dielectric solutions typically consist of two components: a dissolved solid and a solvent. During the spin on process, most of the solvent evaporates leaving a greater than 90% solids content film which is subsequently poly-